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CAR LUBRICATION.

BY

W. E. HALL, B.S., M.E.

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SECOND EDITION, REVISED.

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PREFACE.

SOME years ago the subject of car lubrication became one of much interest to the writer, and, when attempting to acquaint himself with the laws influencing successful practice, he was surprised to find how very little information, either of a theoretical or practical nature, could be obtained. The accompanying pages are not presented as a solution of the question, or as containing any important original research, but rather in the hope that some of the knotty problems which were then presented for solution may be made clearer.

The laws of friction, as accepted until recently, have by later experiments been limited in their application, if not confined entirely, to solids in contact. It is at least certain that they will not apply in any way as the laws governing the friction of solids separated by a lubricant. Prof. Thurston's "Friction and Lost Work," and the experiments of Mr. Woodbury with those of Mr. Tower, are quoted, and several others to a limited extent—to whom, it is hoped, proper credit has been given.

It is desired that these few words may stimulate further thought, and in that way result in a more satisfactory solution of the problem.

THE AUTHOR.

ALTOONA MACHINE SHOPS, *May*, 1891.

PREFACE TO SECOND EDITION.

SINCE the first edition of "Car Lubrication" was published the subject has received some attention by the railroads, as will be noted by the "Report of the Committee on Lubrication of Cars," contained in the Proceedings of the Master Car-Builders for 1894, and the article of Dr. Dudley and Mr. Pease in the February number of *The Railroad and Engineering Journal*, 1892, all of which confirms the conclusions that had been reached by the investigations of the author and set forth in the first edition. The subject, however, has not, by any means, received the consideration it deserves.

Attention is drawn to the continual drift towards the softer metals, and it now looks as though a comparatively hard white metal in shells of iron or hard brass would be finally adopted as the best bearing metal.

In the second edition a number of typographical errors that accidentally appeared in the first edition have been corrected.

THE AUTHOR.

May, 1895.

CAR LUBRICATION.

CHAPTER I.

INTRODUCTION.

IN taking up the study of the subject of car lubrication we shall find it necessary to consider the features in the construction of the car-box and the proportion of the different parts, in addition to the care that should be given to lubrication, so that the journal will be properly supplied with oil and kept in a well-lubricated condition. While there is no reason why it should be so, yet it is a fact that there is probably no other branch of railroad engineering that has been so dependent upon empirical laws and where the practice has been at such variance with the heretofore accepted laws governing it.

The widely taught law that friction is independent of the extent of surface in contact, but varies only with the pressure, is about ready to be placed among the archives of ancient scientists. The pressure inferred in this relationship is that exerted over the whole surface, and not per square inch—that is, a surface one square foot in area under a pressure of one pound per square inch would require the same force to move it over a resisting surface as it would if made one square inch in area under a pressure of 144 pounds per square inch.

The extent of surface in contact was supposed to have no effect upon the force or work of friction necessary to move one body upon another, and consequently required no increased effort to produce motion, provided the same total pressure was exerted although the area of the surfaces in contact might be at variance.

Recent experiments made with various grades of lubricants, to determine the coefficient of friction of lubricated surfaces under varying conditions, prove conclusively that the amount of surface in contact materially influences the work of friction. If the relationship of the "resistance of friction as independent of the area of surfaces in contact, but dependent upon the pressure," were true, the temptation would be to reduce the work of friction and the abrasion of the materials by increasing the area of the surfaces in contact, which would allow the use of a lighter oil by reducing the pressure per square inch without increasing the abrasion. Practical demonstration, however, has proven the necessity of avoiding long journals, and, with the friction of rotation, an increase in the diameter of the journal means a corresponding increase in the work of friction.

While recent investigations have not by any means furnished data that enable the subject of car lubrication to be reduced to the desired degree of efficiency, they give information that is of much value for guidance in the design, construction, and management of lubricated surfaces, and results that will be found to accord quite closely with those obtained from practice. They indicate, and quite conclusively, that when the rubbing surfaces are kept well separated by the lubri-

cant the friction is more dependent upon the nature and fluidity of the lubricant than upon the nature of the solids carrying the load.

There seems to be a combined friction consisting of that inherent in the particles forming the lubricant and of the moving surface in contact with it. With constant pressure and temperature, it is dependent upon the extent of surface in contact and varies directly with it. It is also influenced by the unit pressure, and varies in some ratio with the change in the load, but not in the same ratio as had been previously supposed.

As the resistance of lubricated surfaces is made up of the resistance of the particles of the lubricant, it is evident that any influence that will change the fluidity or density of the lubricant will also affect the frictional resistance.

Increase of temperature, increasing the fluidity, causes a decrease in the coefficient of friction ; while increase in unit pressure causes an increase in the density of the fluid, and, necessarily, an increase in the friction when motion is produced.

The ideal condition of lubrication is attained when the viscosity of the lubricant at the working temperature is sufficient, and no more, to keep the surfaces of the solids apart under the maximum pressure they may have to sustain.

We should always bear in mind that frictional resistance and the abrasion of the surfaces represents an expenditure of money, and, in the aggregate, is of greater moment than is generally supposed.

The subject will be treated in the following chapters by taking up the different parts in detail and then con-

sidering the relationship that must exist to give the most economical results.

It will be considered under the two following general heads:

1st. The proportions and materials that are required to meet the demands of the service.

2d. The most economical way in which these may be applied.

CHAPTER II.

THEORETICAL RELATIONS.

THE resistance of friction in car lubrication is that which is generally known as "sliding friction of rotation." It is similar to linear motion, but, as it is an arc of contact, it differs in the distribution of the load per unit of surface.

When the bearing is first placed upon the journal the arc of contact is small, and it is only after wear has taken place that the whole arc included within the bearing is in contact with the journal. The amount of wear which is necessary to produce this condition is comparatively small unless the radius of the bearing is made much larger than that of the journal, which must be classed as bad practice.

It will be found that the larger part of the pressure is taken at the top of the journal, and decreases in a determinable ratio from that point to the horizontal axis through the centre of the journal. The work of friction is then but a question of the space which is passed over against the frictional resistance which is offered to the rotation. The space in this case is a function of the circumference, and varies as the diameter of the journal.

The law of the distribution of the pressure is as follows:

Let (see Fig. 1)

P = vertical pressure on unit surface;
P_1 = pressure in a radial direction on unit surface;
R = radius of the journal;
ω = angle made by the radius from a point O with a vertical line through the centre of the journal;
l = length of bearing;
L = total load carried.

For any point, O,

$$P_1 = P \cos \omega.$$

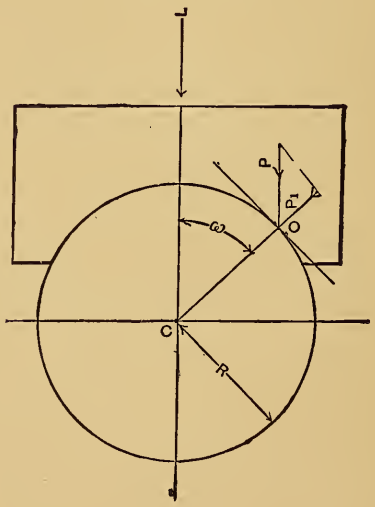

FIG. 1.

The pressure upon a surface $Rd\omega$ is

$$P_1 l R d\omega.$$

The summation of the pressure should be for an equal arc on each side of the vertical, or

$$L = \int_{-}^{+} P_1 l R d\omega ;$$

and by inserting the value of $P_1 l$

$$L = \int_{-}^{+} P l R \cos \omega \, d\omega .$$

From this, the load carried by various subtended arcs can readily be obtained. The accompanying table indicates the relative loads for several values of ω.

Value of ω	Average pressure carried per square inch.	Square inches of surface when radius equal unity.	Percentage carried by the first 10° of the arc.
10°	0.34729	0.1745	100.00
20°	0.68404	0.3490	50.78
30°	1.00000	0.5235	34.73
40°	1.28558	0.6980	27.01
50°	1.53209	0.8725	22.67

It is then evident that a higher percentage of the pressure is taken by a small arc of the journal, and that the lower surface of the arc of contact is the least important part of the distributing surface. It will be noticed, too, that as regards the distribution of the load there is no serious objection to giving the bearings a surface contact that is less than the width of the bearing, for instance a width of bearing surface of three (3) inches on a journal of four inches diameter. It also follows that the practice of boring out the bearing to a greater radius than the journal is open to no serious objection, but, on the other hand, must be done to prevent the bearing seizing the journal, providing

the difference in the radii is not made too great. When this difference is excessive a condition is obtained similar to that shown in Fig. 2, which will result in very poor lubrication and likely produce a heated journal, the sharp corners at *A* having a tendency to scrape the oil from the journal. This effect will be made more apparent further on. In practice it is found that the best results are obtained when the radius to

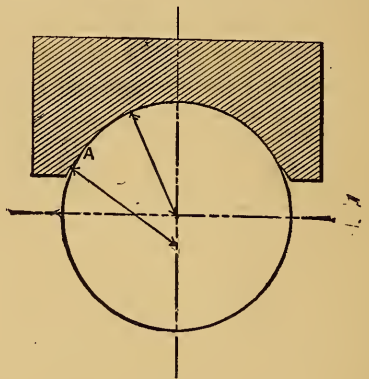

FIG. 2.

which the bearing is bored is about one thirty-second ($\frac{1}{32}$) of an inch greater than the radius of the journal. This gives a safe working margin for a new bearing and journal, and yet does not give too great a difference or opening at the sides of the bearing when a new one is placed on a journal that is worn to the minimum diameter. In cases where journals of different diameters are used bearings corresponding to these different sizes should be kept on hand. In any case the possibility of any heating of the journal on this score can be obviated by using the lead-lined bearings.

Before stating the elements determining the work of friction, it is necessary to review in a general way the results of recent experiments which were made to determine the laws governing the resistance to motion of bodies when separated by a lubricant. Reference is made particularly to the experiments by Woodbury and Tower, the results from both of which, while under different conditions, are corroborative. Those by Woodbury were made with low pressures, and the curves obtained from his results give a relationship of pressure and coefficient of friction, as shown in the diagram, marked as Fig. 3. They show conclusively that frictional resistance, with an intervening lubricant, is not a direct ratio factor of the pressure, as it is with unlubricated surfaces; but, on the contrary, the laws seem to follow those of fluid friction more closely than those of solids. The result produced by the motion of two solids under pressure is a more or less rapid abrasion of the metals in contact. With a lubricant interposed the conditions are quite changed, and follow more closely the resistance which the fluid would offer by its own friction. Whether or no this be a motion of the particles of the lubricant or of the solid upon the surface of the fluid does not concern us. The important consideration is the extent of surface in contact which should enter as an element in the calculation of the work done. The best way for our purpose is to obtain the frictional resistance of the lubricant at the pressure carried, reduced to the resistance under these conditions for a unit surface. The resistance of friction would then consist of two elements: the coefficient of friction per unit of surface for the working pressure

and temperature, and the number of units of surface in contact. Representing these by f and a respectively, would give as the relationship of the total work of friction

$$W = f . a . p . 2\pi R \times n,$$

where

n = number of revolutions per unit of time;

p = pressure per square inch.

With given pressure and temperature the minimum value of the function $f . a$ is determinable.

First, the pressure on the journal and the temperature attained under the maximum speed will indicate the density of the lubricant which it is necessary to use to prevent the surfaces coming in contact, and in the case of car lubrication will vary with the seasons of the year, causing a grading of the oils into those for summer, and lighter ones for winter use. Second, the value of a will depend npon the available space allowed for the journal. It will be seen further on that the results of the experiments indicate that the most economical conditions are obtained by increasing the area, within practical limits, and using a correspondingly lighter body oil for the lubricant.

The value of a for the most economical results is where any further decrease in the resistance by the use of a more fluid oil is counteracted by the increased resistance resulting from the larger surface in contact. More explicitly the experimental results indicate that, within practical limits, a lubricant of greater fluidity and correspondingly lower coefficient of friction can be used by increasing the area, and in that way reducing the unit pressure until the limits are exceeded, when

any further increase of the contact surfaces produces a reverse effect. It will be remembered we found that the additional surface obtained by increasing the arc of contact does not produce a proportionate decrease in the pressure per unit of surface, so that the oil that is selected for the purpose must depend upon the pressure that exists at the top of the bearing. Practically, an arc of contact of some magnitude is necessary for strength and stability, and to give a fairly large area to accommodate for the abrasion which also takes place. Any increase beyond this arc is economical only so long as the increased surface decreases the pressure carried at the centre of the arc to an extent that the lighter oil will, by the consequent reduction in the coefficient of friction, overbalance the increased resistance produced by a greater area. Assuming c as the constant and necessary arc of contact and ω as the desired angle, it is not economical to increase ω when the expression

$$f\frac{\omega}{360} \times 6.282.$$

is greater than

$$f'\frac{c}{360} \times 6.282.$$

f and f' indicate the coefficients of friction per unit of area for the lubricant which must be used to overcome the maximum pressure existing in the two cases which, in one sense, measures the fluidity of the lubricant. This is on the basis of the diameter and length of the journal remaining constant.

An increase in the length of the journal seems to be advantageous, provided it is not carried beyond the

limits placed upon it by practice. The diameter of the journal is dependent upon its length and the load to be carried. Taking the usual expression for a beam supported at one end and uniformly loaded, we have

$$L = \frac{T\pi R^2}{8l},$$

where T = safe ultimate load for the metal, and the other symbols indicate the same as in previous formulæ.

For the deflection we have

$$d = \frac{Ll^3}{2\pi R^4},$$

where d represents the deflection. All are indicated in pounds and inches.

The formula for the variation of the diameter for changes in the length will be used again.

CHAPTER III.

COEFFICIENT OF FRICTION.

WITH the exception of the method of lubrication, there is no other element in connection with the subject under consideration that has received more attention than that of the coefficient of friction, and yet there is no other that is in as crude and indeterminable a state. As investigation progresses, the subject seems surrounded with more and more variables of a complicated nature, which indicate the importance, if not necessity, of the utmost care when the best results from lubrication are desired.

The latest study of the subject has brought out some very interesting results, and has conclusively shown that it is now necessary to at least limit the old laws of friction to dry surfaces in contact, if not exclude them totally. The resistance of friction, when a medium is introduced between the so-called rubbing surfaces, follows laws quite different and more intricate than those determined by Morin, which were to the effect that "friction was independent of the surface in contact, but directly dependent upon the pressure keeping the surfaces together."

Where friction is produced it is important to distinguish between the two conditions to which the two sets of laws apply; in one it is a solid against a solid, the particles of each interlapping and causing resistance by

the efforts of the particles of one metal to tear away those of the other. Where lubrication is introduced it is intended that the two solids shall be separated by a film of the lubricant, generally a liquid. In this latter case the resistance assumes the nature of the laws of fluids, and consists of the friction of the particles of the lubricant and that of the solid against the fluid, forming a combined resistance, the percentage of each to the whole retardation depending upon the nature of the lubricant and the metal surfaces. As long as the metals are prevented by the lubricant from coming in contact, it is found that the friction is dependent upon the fluidity of the lubricant, and varies with changes of this fluid condition, decreasing with a higher temperature and increasing with a less degree of heat.

We will assume, first, that the lubricant prevents any contact of the metal surfaces. The condition then stands between the laws of solid friction on the one hand—that is, independent of the surfaces in contact, but dependent upon the total pressure,—and the laws of friction of liquids on the other, where it is independent of the pressure per unit of surface, but is directly dependent upon the area and increases as the square of the velocity. From most recent investigation this intermediate condition has been found to be, when stated in a general way, that the coefficient of friction decreases with an increase of the pressure, although the total resistance rises directly but not proportionately with the higher unit pressures and increases with the velocity, although not as rapidly as its square. It is also found to be dependent upon the extent of surface in contact. An exact relation between these varying

conditions has not yet been obtained, evidently because they vary so materially with any slight variation in the method used of lubricating the surfaces. As, for instance, when the oil-bath is used the laws of lubricated surfaces, especially as regards surface and pressure, follow those of liquid friction very closely; while with less efficient means of lubrication the results show a condition between solid and liquid friction. This matter will be brought out more prominently in the chapter on the methods of lubrication.

With the surfaces in good condition and the oil-bath method of supplying the oil, which may be considered as practically perfect lubrication, it was found that the mean resistance per square inch of surface, with pressures varying from 100 to 310 pounds per square inch, was as follows:

Lubricant.	Mean resistance in pounds.
Sperm-oil	0.484
Rape-oil	0.512
Mineral-oil	0.623
Lard-oil	0.652
Olive-oil	0.654
Mineral grease	1.048

[Results obtained by Tower.—See *Engineering* for November 16, 1883, and Feb. 6, 1885.]

The speed was 300 revolutions per minute, and journal four inches diameter and six inches long, while the temperature was maintained at 90° Fahrenheit.

A constant temperature is essential for a proper comparison, for in one case the coefficient of friction of lard oil decreased to one third ($\frac{1}{3}$) its value at 60° by increasing the temperature of the lubricant to 120° Fahrenheit.

Probably the most accurate laboratory experiments that have been conducted for the determination of the resistance of lubricating oils were those made by Woodbury for the North-Eastern Cotton Manufacturers' Association, as published in their proceedings of April 28, 1880, and in the proceedings of the American Society of Mechanical Engineers, as contained in volume VI. They were made with the object of appropriating the results to cotton and woollen machinery where low pressures are used, and to that extent are not well adapted to the lubrication of car journals excepting as showing the action of lubricants under varying conditions of temperature and a limited range of pressure. They were presented about the same time as the results of Mr. Tower's experiments, the latter, however, under heavier pressures, but both clearly showing the different conditions under which friction must be studied when solid surfaces are lubricated by such bodies as the mineral and animal oils. It was found in the tests that uniform results could not be looked for unless constant temperature, velocity, pressure, area of surface in contact, and thickness of the film of the oil between the surfaces were maintained, the latter depending somewhat upon the method of lubrication, the results indicating clearly that the resistance of friction was dependent upon and changed with a variation in any of the above conditions. The metallic surfaces were cast iron and bronze, the latter composed of copper 32, tin 2, lead 2, and zinc 1. In one case all conditions were kept constant excepting that of pressure, the diagram represented as Fig. 3 indicating a decrease in the coefficient of friction, with

increased pressure per unit of surface, but an increase of total resistance. Similar tests were made, keeping the pressure constant and varying the temperature, which gave the effect of the variation of the temperature upon the coefficient of friction.

The two diagrams, Figs. 3 and 4, indicate by the two curves the variation which takes place in the coefficient of friction under the conditions named.

In Fig. 4 it will be noticed that the variation in the

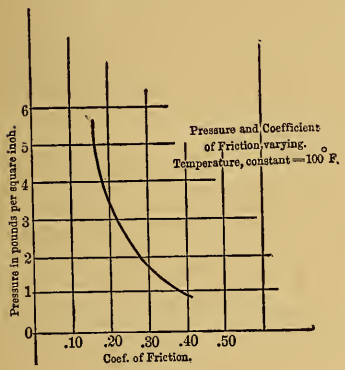

FIG. 3.

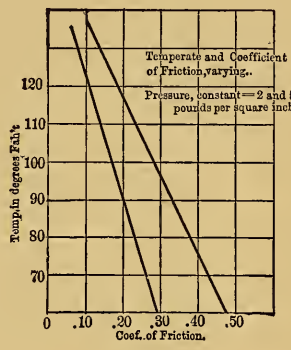

FIG. 4.

coefficient of friction due to changes in temperature follows closely the laws of the straight line, indicating a proportionate decrease with the increase in temperature ; the angle of the line with the abscissæ depending upon the pressure per square inch.

Combining these two diagrams gives a curve, as shown in Fig. 5, for a coefficient of friction where the two elements, pressure and temperature, vary ; and it is this relationship which most concerns the lubrication of surfaces such as car journals, as in this case the tem-

perature is subject to variations arising from changes of seasons and weather, while the pressure carried per square inch is dependent upon how long the bearing has been subjected to wear and attrition, the unit pressure decreasing with increase of service. While the results obtained by Woodbury are the most accurate that have been published and probably ever made, both as regards design of apparatus as well as its manipulation, there still lacks sufficient uniformity for the derivation of a definite law as to the variation of friction with changes in temperature and pressure. For instance, the decrease in the coefficient of friction for pressures of from one (1) to five (5) pounds per square inch is as follows:

Pressure per square inch. Pounds.	Coefficient of Friction.	Decrease in Coefficient of Friction.	Difference in the amount of decrease.
1	0.3818	0.0000	0.0000
2	0.2686	0.1132	0.0000
3	0.2171	0.0515	0.0617
4	0.1849	0.0322	0.0193
5	0.1743	0.0106	0.0216

The decrease in the coefficient of friction from an increase of pressure of one (1) to two (2) pounds was 0.0617 more than that from two (2) to three (3) pounds. while the increase from three (3) to four (4) pounds was 0.0193, and nearly the same as took place when the pressure was increased from four (4) to five (5) pounds.

The above is cited more to prevent a deduction of too wide a nature rather than to deter from the gratitude which the engineering profession must feel for the derivation of the general law of the variation of

friction with lubricated surfaces when the temperature and pressure are varied. The care which it was necessary for Mr. Woodbury to exercise to obtain these results can be appreciated when it was found essential to run the apparatus, using gasoline or its equivalent, to clean an oil from the surfaces after testing. It required a travel of one surface over the other equivalent

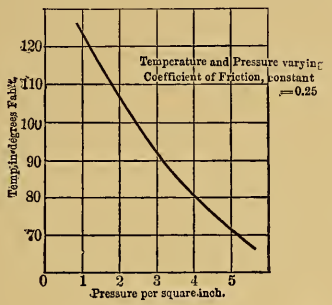

FIG. 5.

NOTE.—The coefficient of friction in the three cases is represented in actual pounds resistance.

to about forty (40) miles before it was advisable to commence the trial of the succeeding oil, and even then indications could be noticed in the test following of the properties of the oil previously tried. This is considered further evidence that the friction of lubricated surfaces is made up of the friction of the fluid, and tends to prove that the lubricant imbeds itself into the surface of the metal, producing a fluid resistance rather than a resistance due to the rubbing of the surface of the metal upon the surface of the lubricant. This effect will be taken up again in the chapter on Bearing Metals.

The variation in the coefficient of friction with changes of temperature can readily be carried to an extreme, as it has been found that while the resistance decreases as the temperature is raised, there is a point, depending upon the unit pressure and viscosity of the lubricant, where the coefficient starts to increase very rapidly with increase of temperature. The same holds true with a variation in the pressure; and while the laws of changes are true as stated, in a general way, they depend and are limited by the viscosity of the lubricant used, and also the pressure which it is necessary to carry. The rapid increase, when the limits of temperature and pressure are exceeded, is due to the solids coming in contact and causing increased friction by the abrasion of the surfaces, reducing the condition from friction of fluids to that of solids.

An attempt has been made to prove a positive relationship between the viscosity of an oil and its coefficient of friction; and while they are, no doubt, more or less dependent, there is hardly sufficient data at hand to resolve this to a definite basis. In addition to that of viscosity lubricants possess a property designated as unctuousness, which seems to influence the coefficient of friction as much, if not more, than the viscosity. It appears, and there seems sufficient information at hand to anticipate it, that a relationship of a positive and determinable nature between the three elements, coefficient of friction, viscosity, and unction, is obtainable.

The results of the experiments made by Mr. Tower, as presented before the British Institute of Mechanical Engineers, are of such a nature that they can readily be converted into practice with a resulting profitable

application. They go to corroborate, to a close degree, the results of Mr. Woodbury, although they have the advantage of having been made with higher pressures. It should be remembered that with high pressures, such as those obtained before seizure takes place, the film of oil separating the bearing and journal has been found to be very thin, and shows the result that may be expected where the irregularities or projections on the surface of the bearing are greater than the thickness of the film of oil used to separate them, producing when in motion a rapid and detrimental abrasion of the metals with a marked increase in the friction. It would not be safe to allow the irregularities to project from the surface more than the thickness of the film of oil, unless, of course, the prevailing area is of this height. The other extreme, of having the surfaces too highly polished, must also be avoided, as it has been found that a moderately rough machined surface will carry something like seven (7) times more pressure before seizing than can be obtained from highly polished surfaces. The proper condition would seem to be about that produced by a boring tool, except with the soft metals, which, from their nature, are incapable of taking a high polish.

For the purpose of comparison let us consider briefly some of the results obtained by Mr. Tower where the journal was lubricated by the oil-bath method and the surfaces were in good condition. Assuming a loaded car of total weight of 80,000 pounds would give 10,000 pounds per journal. At a pressure of 300 pounds per square inch this would require a bearing area of 33.33 square inches to carry the load. With

the resistance given for mineral oil of 0.623 pounds per square inch on a journal 4 inches in diameter and a wheel 33 inches in diameter, a tractive resistance of 2.52 pounds per journal, or of 0.504 pounds per ton, would be required after motion had been produced. With the latest dynamometer readings the resistance of journal friction for loaded cars will probably reach as low a figure as 2 pounds per ton on level tangent when running at a speed of 15 miles per hour. Retracing, this figure gives a journal resistance of 82.5 pounds, and as high a figure as 2.48 pounds per square inch of bearing contact. It will be seen how low an efficiency is obtained in practice, but it should be remembered that the above laboratory tests were with the oil-bath method of lubrication, which has proven, when so tried, to be far superior to any other method that is at present known for lubricating surfaces. In most cases it has been found that the resistance of friction is a direct proportionate function of the area of surfaces in contact; twice the bearing surface, all other conditions remaining the same, will give, approximately, twice the resistance from friction.

The information as presented by the theoretical tests of oils is of much importance in the selection of the one best suited for the conditions of any particular service. In car lubrication, however, a constant relationship between bearing surface, lubrication, temperature, and pressure does not exist, and for that reason a large factor of safety must be used to cover the variations and the extreme conditions that exist in practice. For instance, when starting with a new bearing, the surface in contact is much less than when it has worn

down to a point where the whole arc of the bearing comes in contact with the journal. This is one of the conditions which must be met, for with the irregularities of the parts accompanying the distribution of the load it is found, excepting with the so-called soft-bearing metals, that heating will almost invariably result if the bearing is fitted to the journal throughout the whole arc which it is capable of including. There seems to be a binding action on the journal. If the bearing is so fitted as to allow a small amount of motion of the bearing on the journal, the wear will take place in a manner consistent with the alignment of the journal-box. The variation in the unit pressure is not, however, as wide as would at first be supposed, as will be seen on reference to Chapter II, where the variation in unit pressure due to changes in arc of contact is given. The viscosity of the oil selected should, then, be such that it will keep the surfaces apart under the conditions of minimum arc of contact, and at the highest temperature that will be met. This temperature is not dependent altogether upon that of the atmosphere, but, on the contrary, will vary much with the nature of the service. For instance, with long continuous fast runs the temperature of the journal will be considerably above that of the atmosphere. With this service the heat arising from the work of friction will be such as to raise the temperature of the journal and bearing before a constant condition is reached, and the conductivity and radiation of the heat through and from the surfaces is not sufficiently rapid to accommodate for all the heat generated, and keep the temperature down to that of the atmosphere. It will not be found un-

common for journals in severe service to reach a temperature of a hundred and fifteen (115) degrees Fahr. with the atmosphere only 50 to 60 degrees. This results in better lubrication, provided an oil has been selected with sufficient body to meet the conditions. If such is not used, the parts are reduced to such a sensitive state that the slightest cutting from the entrance of foreign matter between the bearing surfaces is apt to result in an overheated journal, or what is generally known as a hot box. The maximum presure per square inch that must be sustained without seizure at the highest temperature that will be reached will determine the grade of the oil which it will be necessary to use. The resistance is a minimum when the product of the coefficient of friction and the area in contact is a minimum. When the limitations of the case require the use of high unit pressures, correspondingly heavier oils must be used to prevent the bearing seizing the journal; but that oil, all other variables remaining the same, which will give the lowest coefficient of friction and prevent the surfaces coming in contact is the one to be used.

The work done is dependent upon the circumference of the journal, so that any change in its diameter affects correspondingly the work of friction. The diameter of the journal varies closely as $\sqrt[3]{l_1}$. The work of friction is dependent upon the coefficient of friction per unit of surface, the area in contact, and the distance travelled; or, depends upon

$$W = \pi a f n \sqrt[3]{l_1}.$$

Assuming a constant deflection, the variation in the

diameter is that necessary to maintain strength for the changes in the length. By referring to the table on page 15 it will be seen that we can determine the intrinsic values of the heavy and light oils on the basis of the work of friction, resulting from the resistance which each offers to motion. For instance, Tower found that with rape-seed oil the pressure which it would resist up to the point of seizure was 573 pounds, and with mineral oil a pressure of 625 pounds per square inch. To make a comparison between sperm oil, which is of still lighter body, and mineral oil we would have, assuming a proportionate power of resisting pressure, 541 pounds pressure as the capacity of the sperm oil. Taking this oil, and with a bearing surface of $1\frac{1}{2}$ by 8 inches, we find it would require for mineral oil $\frac{1\frac{1}{2} \times 8}{x} = \frac{625}{540}$ or 10.4 square inches of surface to sustain the load. The corresponding length would be 6.9 against 8 inches with sperm. The expressions for the work of friction in the two cases would be

$$W = \pi a f n \sqrt[3]{l_1};$$
$$W_1 = \pi a' f' n \sqrt[3]{l_1'};$$

and their ratio

$$= \frac{f a \sqrt[3]{l_1}}{f' a' \sqrt[3]{l_1'}} = r.$$

Sperm oil $= f = 0.484$, $a = 12$, $l_1 = 8$;
Mineral oil $= f' = 0.623$, $a' = 10.4$, $l_1' = 6.9$;

$$r = \frac{112.73}{123.75} = 0.911.$$

While some of the figures are approximate only, they are sufficiently close to show that the heavy oils, even with the decrease of bearing surface which they allow are not as economical as the lighter ones, so that it may be stated in a general way that the work of friction is least where the conditions are such that they will allow an increase in the length of journal, resulting in an increase of the bearing surface under the same load, when an oil of lighter body may be used.

This conclusion has, of course, its practical limits, and it would probably require modification if experiments of a more detailed nature were made on the same lines as started by Mr. Tower, but would not, in all probability, change the general result. It clearly shows the importance and value which must be attached to further investigation in this direction.

CHAPTER IV.

BEARING METALS.

OIL and bearing metal, in their relation and application to car lubrication, are capable of almost unlimited treatment, so much so that it has now become the work of a specialist to properly follow each and advise as to their efficiency. The easy adulteration of oils make them a subject of suspicion and necessitate rigid specifications and inspection to eliminate the chance of such deterioration. This having been successfully accomplished, through proper specification and rigid inspection, the next point is the selection of the oil best suited for the journals to be lubricated. This requires the consideration of properties, in addition to the coefficient of friction. Those referred to are the rate of evaporation at the working temperature, the tendency of spontaneous combustion from the evaporation, the decomposition of the oil by the atmosphere, and, still further, that of the chemical action of the acid, which animal and vegetable oils contain to a greater or less extent, on the metal used for the bearing.

For instance, an oil, whose exposed surface gave an evaporation of 20 per cent would be far inferior to one which gave but 10 per cent evaporation at the same temperature and in the same time. It is also objectionable on the ground that the oil giving the higher

evaporation would also be more liable to give trouble from combustion arising from the rapidly vaporized oil. Care must be taken not to conflict the flashing point with the rate of evaporation, as they are not in any way related, for it has been found * that, in one case, two oils having the same flashing point gave the rate of evaporation of 9.4 and 24.6 per cent respectively. When determining the percentage of evaporation of oils, the surface, time, and temperature should be the same in all cases, as otherwise it would not be a true comparison. The mineral oils have a low evaporation, and when mixed with those of an animal and vegetable nature prevent, to a large extent, the spontaneous combustion which is apt to result and give trouble when the animal or vegetable oils are used alone. The chemical effect arising from exposure to the atmosphere is of much importance in its influence upon the lubricating value. This action, with the fine particles of dust or foreign matter which enter through the front and back of the box, reduces the oil in the top of the waste to a pasty condition which materially depreciates it as a lubricant. It should be remembered that the result obtained by the use of an admixture of the mineral and animal oils is dependent upon their relative proportions and the temperature to which the mixture is subjected. The use of the petroleum products has a remarkable effect toward reducing the tendency to inflame, so common when the animal and vegetable oils are used alone. The relative value of oils on the basis

* See Prof. Ordway, in Proceedings of Semi-annual Meeting of N. E. Cotton Manufacturers' Association, held in Boston Oct. 30, 1878.

of percentage of evaporation and inflammability is unknown; in fact, it is as yet an undeveloped field, but represents properties which must sooner or later enter as factors in the efficiency of an oil for lunricating purposes. The importance of these will be appreciated from the results which Ordway found, where with one oil the evaporation in twelve hours, at a temperature 140 degrees (Fahr.), was 24.6 per cent.

As well, too, should the question of the chemical effect of the acids in the oil be taken into consideration. For these two reasons, lower evaporation and freedom from acid, the mineral oils are coming into general use for car-lubricating purposes, while they also give, from their lubricating qualities, as low a coefficient of friction as any of the animal or vegetable oils. They can be obtained of almost any desired gravity and fire test, and, when clean, are particularly well adapted to the service in question.

The brass-foundry practice of to-day is still so much dependent upon empirical laws that it is impossible to reach any definite or concise conclusion as to the exact nature of the alloy, all things considered, which gives the best results for car-bearings. So much depends upon the foundry treatment that a chemical analysis is of very little value from which to draw any definite conclusions as to the nature of the service which a known mixture of metals will give. The same ingredients differently treated will give alloys of marked variation in their physical properties, and until the foundry working can be reduced to a more accurate science we must be subjected to the so-called "kinks" which have in some cases produced metals of remark-

ably good wearing qualities. This is illustrated in phosphor bronze, where the metal as produced contains about 0.75 per cent of phosphorus, while about one (1) per cent is used during the treatment. The effect of the phosphorus is to produce a more solid casting by reducing the amount of oxidation which takes place during the mixing of the metals, but the presence of the phosphorus in the metal after melting has no effect upon the quality.

The metals used for bearings may be classed about as follows: phosphor bronze, brass, and the so-called white metals, the latter containing a large percentage of lead, zinc, tin, or antimony, with but little or no copper.

Each has a wide range of hardness, but from all that can now be gathered, the white metals give excellent service and wear less than the harder alloys. In 1883 the writer had an excellent opportunity to compare, in a general way, the service of a hard bearing with one composed of antimony and lead,—the latter material was run into an iron shell. The two roads using the metals were located in the same part of the country, started from the same place, and had the same destination; in fact, they paralleled each other for a large part of the distance, so that the service was as nearly alike as it is possible to obtain for a comparison. The bronze required, on an average, a consumption of oil of 0.945 of a pound, and the white metal an oil consumption of 0.3075 pound, each, per car per 100 miles. Where the bronze was used it was necessary to resort to lard oil, making the cost per car per 100 miles in the two cases

6.3 and 0.88 cents respectively, nothing but common black oil being used with the white metal.

The white alloy was remarkably free from heating, while with the bronze bearings hot journals were giving continual annoyance.

As regards the wear of the soft and hard metals, the experience with bearings lined with lead alone indicates the remarkably long service which can be obtained from even a lining but $\frac{1}{16}$ of an inch thick. Experiments as given in the *Railroad Gazette* for March 5, 1886, are much in favor of the white metals.

There is some difference of opinion as to the resistance of friction, as well as their effect upon axle wear, with the red brass or equally hard-bearing metal, and the so-called white metal, but, as far as is known, no experiments have been made giving results by which a comparison can be drawn to determine the efficiency of these two features of the metals. Research with this object would be of much value. As regards axle wear, however, it will be seen, by reference to the chapter on the cost of lubrication, that bearing metal and axle wear are almost equal in value for the loss resulting from abrasion per 1000 miles. With soft and hard metals moving together the result is always a more rapid abrasion of the harder one. This is where the surfaces are separated by a grinding material; but when properly lubricated the condition is quite different, as then the separating material is fluid and slow in its wearing action, and, from the experience of those who have the white metal in general use, the wear is not increased by the particles of dust which its opponents

claim become imbedded in the bearing, and in that way exercising an additional grinding action upon the journal and increasing the wear over that produced by the harder metals.

While there seems no reason to expect a more rapid wear of the journal from the softer metals, yet it is a subject seriously affecting the cost of lubrication, and one upon which there is lacking sufficient information to warrant the positive assertion that the softer metals are superior to the harder ones for bearings. Experience so far, however, seems to be in favor of the white metals. This much can certainly be said that a large part of the cost of lubrication of cars where the harder bearing metals are used is due to the loss resulting from heated journals, and the white or softer metals invariably give less trouble from this cause than any other alloy that has yet been made.

There has been a tendency to attribute the metal contained in an oil that had been in service solely to the wearing of the bearing, but the experiments of Volney will show the relative action of different oils upon the decomposition of brass. The figures also represent the value of the oils in this respect, and, together with the oxidation which results from exposure to the atmosphere, indicate the influence which these properties have in producing the pasty condition of the waste. The dissolving power should be considered in its relative importance in the selection of the oil that is to be used. It also shows that the bearing metal found in the oil of a journal-box is not all due to abrasion.

Attention is drawn to the low dissolving power of the crude petroleum oils, another property that should fa-

vor the use of these oils for car lubricating purposes. On the whole they will maintain a more uniform condition, and they have fewer detrimental properties than oils of either vegetable or animal origin.

Name of Oil.	Relative Dissolving Power.
Menhaden oil	0.511
Neatsfoot "	0.505
Olive oil	0.504
Crude cotton-seed oil	0.348
Lard oil	0.131
Crude petroleum from Scio	0.000

NOTE.—For general results of tests of bearing metals and oils made on the Paris-Lyons-Mediterranean Railway, see appendix containing translation from *Revue Générale des Chemins de Fer.*

CHAPTER V.

METHODS OF LUBRICATION.

THE devices that have been designed and the so-called inventions that have been patented to lubricate car journals are innumerable, and yet there is not one at present in use that can be said to be in such a stage of development as to promise superiority over the method of using cotton or woollen waste when this is properly arranged and manipulated.

The writer has had experience with numerous devices, most of which were arranged to lubricate from the under side of the journal. The nature of such devices was various; some were made up of a revolving cylinder in contact with the under surface of the journal, while the lubricating mechanism ran in oil. The roller, when such is used, receives its motion from the journal in which it is kept in contact by a spring or some similar arrangement. Devices of this general nature have been made in numerous quantities, all differing only in some minor detail. None of them have been known to produce satisfactory results. Mechanical methods in the nature of pads kept in contact with the journal by springs have been tried, but from a thorough test the results seem to indicate that the elasticity of the waste commonly used is superior to the mechanical devices, not only in the quality of the lubrication, but also in the mileage rendered. One case is

known where an attempt was made to lubricate by feeding oil through the top of the bearing, and by waste at the bottom of the journal, similar to boxes used on foreign roads; and although the trial was of short duration, no apparent advantage over the method now generally used was noticeable. Devices have also been attached to the front of the journal for lifting the oil to the bearing, some of which have proven fairly satisfactory. In fact, the possible methods of lubricating car journals are innumerable, but with any mechanical device the objection which can be predicted with a fair degree of certainty is the annoyance and expense that would result from even a small percentage of breakages. The number of hot boxes, when figured on a percentage basis, is exceedingly small and less, it is believed, than can be obtained by any mechanical device, however simple its construction may be. We may except the so-called roller bearings, which have been tried with more or less satisfaction in an experimental way. The theoretical advantage arising by resolving the friction from that of sliding to that of rolling would appear to be a large gain; and yet from the experiments of Wellington (see Proceedings of American Society of Civil Engineers) it would appear that this advantage is indicated only during starting, but is not so large a percentage gain after the velocity is increased. Roller bearings have been known to run successfully for 100,000 miles, but it is not known that they have been subjected, by a more general introduction, to an extensive trial to determine their mechanical efficiency, such as wear and tear, and comparison with sliding friction with the surfaces separated by a lubricant.

The results of Tower's experiments, previously referred to, give a close idea as to what is to be expected of the different methods of lubrication. It was found with three (3) methods of lubricating journals, feeding the oil from below and from above the journal, that the following ratios of their efficiencies will result:

Method.	Actual Load. Pounds per sq. inch.	Coefficient of Friction.	Comparative Friction.
Oil Bath.....	262	0.00139	1.00
Siphon Lubricator.....	252	0.00980	7.06
Pad under journal.....	272	0.00900	6.48

The siphon lubricator was placed on the top of the bearing. The tests were under the same conditions. Rape-seed oil used. Journal, 4 inches diameter, running at a speed of 150 revolutions per minute. Temperature 100 degrees (Fahr.).

There can be no question, then, as to their relative efficiencies. The oil-bath method has had numerous trials upon car journals, but has always proved a failure from the difficulty of obtaining a mechanical means that would retain a tight joint at the back of the box unless it be made of such a complicated nature as to outweigh, on account of repairs, the advantages accruing from the method. The siphon method has objections on account of the high resistance offered, the cause for which will appear further on. It can safely be concluded that the use of a pad under the journal gives a higher resistance than would be obtained with what is known as waste, due to the closer texture which its name implies. This gives it less power to

absorb the oil, the importance of which is evident from the high efficiency obtained with the oil-bath method of lubrication. Two surfaces that fit tightly when dry can be made to move easily on one another by interposing a lubricant. It would seem, with the resistance arising from the tight fit when dry, that the introduction of additional material between their surfaces would offer still more resistance to their motion. The application is so common that the reason why it should be so is generally lost sight of. With this exceedingly thin layer of oil, whether in the nature of globules which have penetrated the pores of the metal, or a continuous layer of the lubricant between the surfaces, the result indicates the strength of the wedging action between the metals in contact which enables the lubricant to be introduced. This is quite the same action as when lubricating by means of an absorbent material which is saturated with the lubricant and placed in contact with the lower side of the journal, unless the bearing grips the journal and scrapes the oil from the surface, in which case the object is defeated. With journal friction, from the nature of the distribution of the load, it will be noticed, by referring to Chapter I, that the radial pressure of the journal increases from zero, when the bearing includes a semicircle, to a maximum which is on a vertical line through the centre of the journal; that is to say, the nature of the distribution is such as to make the action the same as that of a wedge even when the bearing is in contact throughout the whole of its arc. It is an increase from a minimum to a maximum pressure per unit of surface. The results of Tower are practical demonstrations of this effect.

During the progress of the experiments with the oil-bath method of lubrication he had occasion to remove the bearing. It was then decided to insert a lubricator in the top of the bearing, for which a $\frac{1}{2}$-inch hole was drilled. After re-starting the experiments and before the cups were inserted in the top, oil was observed to rise in the hole which had been drilled, and was noticed to exude at considerable pressure, which, when indicated on the guage attached to the top of the bearing, was found to be more than 200 pounds per square inch, while the average pressure (vertical) upon the bearing was 100 pounds per square inch. It was further found, when a groove was cut the whole length of the bearing and a lubricator attached to feed oil to this groove, that even with a pressure of seven (7) inches head of oil, it would not feed to the bearing, but, on the contrary, it appeared to be the means of escape for the film of oil between the bearing and the journal. When the cup lubricator was the only feeder, the bearing would not run cool with the pressure as low as 100 pounds per square inch. In this case, care was taken to chamfer the edges of the groove to prevent any scraping action. As the point of application of the lubricant was moved from a vertical towards a horizontal position, the friction decreased and the bearing was found capable of carrying greater pressure before seizure. The experiments by Tower to determine the pressures at different parts of the bearing are so indicative of the wedging action which takes place that they are referred to somewhat in detail. The bearing was divided into three (3) vertical planes lengthwise of the bearing, and

each half into three (3) planes at right angles to the first ones.

The lubricator was placed on the intersection of the planes passing through No. 0, No. 1, and No. 2, and

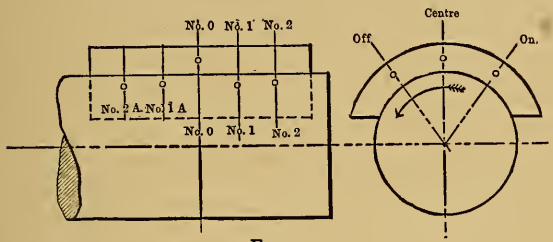

FIG. 5.

the same pressures assumed for No. 1 A and No. 2 A —rather an unfortunate assumption, especially as the means of distribution may have had an effect upon the pressure at the points on the rear half of the bearing. The results were as follows:

Longitudinal Planes.	On.	Centre.	Off.
Transverse Plane No. 0....	370	625	500
" " No. 1....	355	615	485
" " No. 2....	310	565	430

The figures represent in pounds the pressure per square inch. The bearing had a total load of 8008 pounds, the journal running at a speed of 150 revolutions per minute. Temperature constant at 90° (Fahr.). Journal 4 × 6 inches.

The maximum pressure was at the centre, as was to be expected; but the increase on the off side of the bear-

ing would go to indicate that the wedging action is so dominant as to actually skew the bearing on the journal, and would do so where there is clearance between it and the sides of the box to allow of any such motion. That such results are shown by experiments, while in practice this method of lubricating from the top of the bearing is giving more or less satisfaction, can be attributed only to the effect of the end play of the bearing on the journal, and to the change in position when the bearing and journal are not as closely fitted as was the case with the apparatus which Mr. Tower used and which was probably necessary for the nature of the tests which he made. It then becomes apparent that the method of oiling from the under or exposed part of the journal is by no means the most inefficient one, but, on the other hand, seems to be the best way of introducing the lubricant. Inasmuch as the oil-bath method has been found impracticable, the result obtained by it is a favorable indication that the use of waste placed under the journal as now practiced is capable of giving highly efficient results. To obtain the very best effect in this way, however, it is necessary to observe a number of the details of the method. For instance, when using new waste it is important, in fact necessary, to thoroughly saturate it before placing it in service, which will be clearly seen from the following experiment. With one road it was the practice to oil journal-boxes of passenger equipment cars at the end of each of the sub-divisions of a main line with the object of preventing the occurrence of heated journals and assuring the condition of good lubrication. To test the necessity of this method a car was selected, the journal-boxes of

which were carefully cleaned and repacked with new waste which had, for some few hours only, been thoroughly soaked in oil. For some two hundred miles of the run after repacking, the journals were very warm and had almost reached the point where scaling of the surface of the bearing takes place. No oil was placed in the boxes, however, especially as it was found that the journals seemed to become cooler as the distance run was increased. The car was taken some four hundred and fifty (450) miles out, when the journals were very cool and reached their destination in good condition. The car was returned to the starting point, and it afterwards made a second round trip, covering in all eighteen hundred (1800) miles with one oiling, and yet at the start it seemed as though the car would not succeed in covering more than one hundred (100) miles before trouble would arise. The warm condition of the journal and surrounding parts increased the fluidity of the oil and enabled the waste to more easily absorb it and exercise its capillarity. That the waste at the end of the second round trip was still in good condition partly indicates what can be accomplished by systematic attention, although the trial does not indicate a successful but rather a dangerous way of saturating the waste. It is cited to emphasize the importance of having the waste well saturated before placing it in boxes. In a short paper read by the writer (see Proceedings of Engineers' Club of Philadelphia, fall of 1886) there is given the result of a crude experiment made with the object of roughly determining the absorptive powers of fibrous and woollen waste. A small quantity of dry woollen waste was taken, one end of which was placed

in a large cup half filled with oil, and the other end, after passing over the top of the cup, was allowed to pass down the outside and rest upon a table. After standing some twenty-four (24) hours, the waste was oily to the touch and a small oil-spot was found upon the table. The waste was allowed to remain in this condition for some two (2) or three (3) days, but seemed to absorb but little if any more of the oil, indicating the almost inappreciable effect of capillarity in comparison with what is already known as its absorbtive power. When the best results are desired from this method of lubrication, the necessity of thoroughly saturating the waste, that is, covering it with oil for some days before using, becomes apparent. The object should be to produce with waste, as near as can be obtained without incurring the loss resulting from splashing, the condition known as the oil-bath method of lubrication. To obtain such a result we cannot depend much upon the capillarity of the material. The condition to give this end is, it seems, to obtain a state of saturation such that the journal is continually replenished with oil as it revolves. The degree of saturation will decrease from that at the bottom of the box to the top of the waste. The top of the waste should contain an amount of oil just below the state, where it will run from the back or front of the box, hence the advisability of having these points as nearly oil-tight as practicable; they not only reduce the loss of oil, but also render a lower resistance from friction. The small amount of dependence which can be placed upon capillarity can also be tested and proved by an examination of the waste of a journal-box which has

been in service some months. That at the front will be found to be much better saturated with oil than the waste at the back of the box. For this reason it is thought the oil should be introduced into the box at some point about midway of the journal, which can be readily done by small openings in the front and leading back by cored passages to any point where it is desired to bring the oil in contact with the waste.

CHAPTER VI.

JOURNAL-BOX CONSTRUCTION.

Many types of journal-boxes have been designed, but very few of these have carried all the essential features that go to make up a good, efficient journal-box. For instance, some have devoted all their attention to the construction of the rear end or dust-guard part of the box, while others to the front or lid, and so on.

The distribution of the load, however, seems to have received less attention than any other feature. It is unnecessary to give a historical review here of the numerous devices which have been tried to make the box dust- and oil-tight; but suffice it to say that efficient means to accomplish these results, especially for the back of the box, are too much overlooked. A good dust-guard seldom proves a bad investment; it should, however, be simple in design and of a material that will not be affected by the oil. It should also accommodate itself to any wear of the bearing.

The method of distributing the weight upon the bearing is an interesting analysis, and, if not carefully followed, will produce results from which considerable trouble may arise. From the conditions of the case it will be well understood by those at all familiar with the design and nature of the mechanical appliances used for carrying the weights of cars that mechanical accuracy in the parts cannot be obtained. Especial

reference is made to the condition of the seat in the top of the box and the top of the bearing, both of which are rough castings, and, however, clean and accurate these may be in the rough, it is impossible to obtain a condition for the distribution of the load such as can properly be expected from finished surfaces. In one of the designs which has come under notice the weight was thrown on the centre of the bearing, as shown in Fig. 6. Notwithstanding the bearing-metal

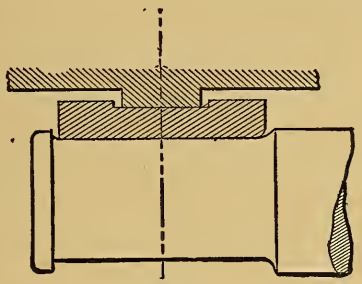

Fig 6.

was as strong as any known to the trade for such purposes, the result of this design, after some years of service, gave positive and decided indications of hollow-worn journals, due to the springing of the metal at the ends, as would naturally follow from this method of distributing the load. Fig. 7 indicates the result, exaggerated, to which reference is made. It may be safely inferred that to obtain sufficient strength of the bearing to prevent the journal wearing hollow when the load is distributed in this way, would require a thickness of metal much greater than when the distribution is more even or uniform. Other objections to this in-

crease of the weight of the bearing will be found in the chapter on the Cost of Lubrication.

The prevailing practice in the distribution of the load upon the journal is that shown in Fig. 8, where, in

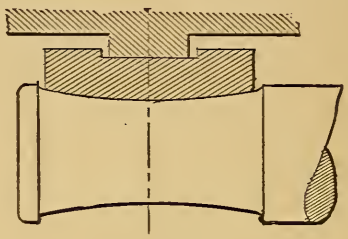

FIG. 7.

theory, the weight is uniformly distributed over the whole top surface of the bearing. In practice, however, the result is quite different from this, as will be readily seen by an examination of journals which have been used with this design of box. Instead of a uni-

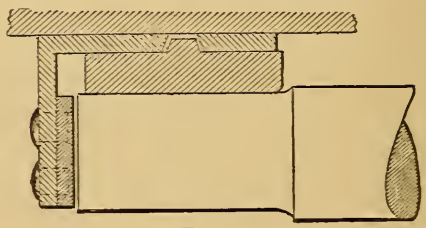

FIG. 8.

form wear, it will be frequently, if not generally, found that the journal is worn small either toward the inside or outside end, showing conclusively that most of the weight is thrown in either of these two directions. An analysis of the conditions will give sufficient cause for

this result. The design indicated by Fig. 8 is that used by a number of the railroads, and is probably more favored than any other construction of journal-box.

When all goes well uniform wear of the journal can

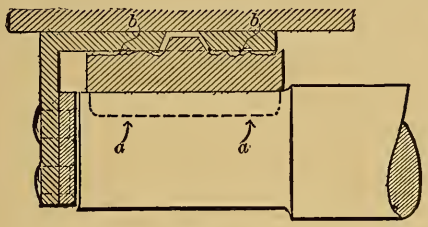

FIG. 9.

be safely looked for; but when considering that the top of the bearing is an unfinished casting, it is not surprising to find the load actually taken as illustrated by Figs. 9 and 10; the conditions shown in Fig. 9 illustrating the effect of irregularly distributed high spots.

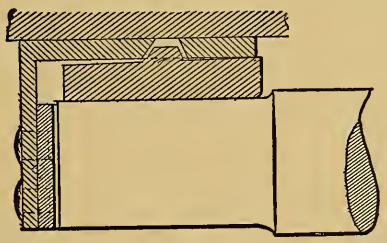

FIG. 10.

That shown in Fig. 10 may arise from one or two causes: 1st. When the top surface of the journal-box is not parallel with the plane of the top of the bearing and the desired line of contact. This may arise from bad alignment of the box or lack of parallelism in the

rough castings. 2d. From a journal worn small at the front end. It is evident that the positive prevention of the first of these two causes would require a grade of refinement which present practice cannot meet.

When considering Fig. 9 it should be remembered that three (3) points determine a plane, the exaggerated roughness of the top of the bearing indicating a possible if not a probable condition. As the bearing is held during the boring by the top surface and the bottom edges, it is best, with this method of distributing the load, to roughly dress these edges, *a*, *a*, making them as nearly parallel with the surface *b* as possible, so that the bored part will be parallel with the top.

The defective distribution of the weight arising from lack of good alignment, and particularly irregularities in the rough castings, can, of course, be partly overcome by finishing the fitting parts, but involving thereby an expense which the conditions of the case would hardly warrant. It would seem, however, that by the method indicated in Fig. 11 the trouble would be alleviated without any increase in the refinement of the fitting parts. It will be noticed that provision is made to accommodate and meet the two prevailing objections to a good distribution of the load, and by finishing the edges, *a*, *a*, parallel with the top surface—the grinding of which is quite sufficient,—a more uniform equalization of the load can be obtained, and maintained with whatever changes may take place in the position of the box. It is seen that the bearing is loaded similarly to the method shown in Fig. 6, excepting that the free ends of the bearing are of less than half the length, and would not cause sufficient unequal wear of

the journal to prove a practical objection. It should be remembered that the deflection of a beam varies as the cube of the length. When carrying the load in this way it is not at all necessary that the top of the bearing should be parallel with the top line of the journal.

Stress has been placed on the method of distributing the load, and it is very apparent that it is much influenced by the device used for transmitting the weight to the journal. Its effect is quite apparent in increasing the pressure per square inch on a small part of the journal, necessitating the use of an oil of higher resist-

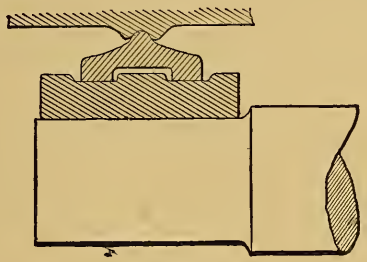

FIG. 11.

ance than might otherwise be used. More than this, the effect is to wear the journal unequally, and in that way render it unfit to receive a properly prepared bearing when it is necessary to renew one. As regards the latter objection, if the bearing and journal were of equal life, and considering only the condition after the brass had worn to sufficient bearing surface to carry the load without excessive abrasion and resulting heating, it would be of less importance as to how the weight was distributed ; but when the journal, on an average, outwears some half dozen or more bearings, it becomes

correspondingly difficult to renew the bearings without encountering considerable annoyance from the condition into which the journal has been worn by a load that has not been properly distributed. It is hardly strange that under such conditions delays from, and expense of, hot journals are encountered. It is rather surprising that there is so little trouble.

With the object of meeting these mechanical defects, Hopkins applied a lining of soft metals, generally lead, to the under side of the bearing, by which it can adjust itself to unequally-worn journals, and thereby render a larger surface for the weight than can be obtained when a more rigid metal is placed upon the journal. The arrangement, though patented at the time, was a most excellent one, and has given admirable results when properly applied to the bearing. It also assists in meeting the decrease in bearing-surface, which arises when a new bearing is placed upon a much-worn journal. Care should be taken, however, to obtain the proper thickness of the soft metal lining which has been found to be about $\frac{1}{16}$ of an inch. When more than this is used the lead is forced out at the edges of the bearing, and prevents the oil getting between the surfaces, and in other ways produces trouble.

As the Hopkins patent has expired, a description of the way in which the lining is done may prove of value to those who are anticipating the lining of bearings.

The operation is as follows: The bearings are first bored. As they are to be treated for lining, they are first placed on a coke-fire and allowed to become well heated, when they are cleaned with muriatic acid and

tinned. They must then be warmed again so that the tin is in a condition for the lead to adhere to it. They are then placed on a mandrel to receive the lining of lead. The device for holding the bearings during the lining can be made of very simple construction. It should be so designed that the bearing can be clamped only centrally with the mandrel, which will make the lining of uniform thickness over the bearing. The radius of the mandrel should never be more than $\frac{1}{32}$ to $\frac{1}{16}$ of an inch of the radius of the journal which the bearing is to fit. The lead lining should never, however, be more than $\frac{1}{16}$ of an inch thick; and to insure this result, the mandrel for the particular diameter should be such as to prevent more than this amount between it and the bearing. The quantities of materials to line bearings with lead, at the present market prices, are as follows:

TO LINE ONE HUNDRED (100) BEARINGS.

Material.	Amount in Pounds.	Cost in Cents.
Lead	60	285.0
Lead and tin for "tinning" (half-and-half)	4	70.0
Muriatic acid	0.4	0.6

The labor should not amount to more than two or three cents per bearing, as it does not require much skill for this work.

The value of this lining as a bearing metal has been stated at figures, both high and low, but no reliable definite figures are at hand.

As a soft metal, however, it will give excellent wear, which point has already been brought to notice in the chapter on Bearing Metal.

CHAPTER VII.

COST OF LUBRICATION.

THE representation of journal friction in actual dollars and cents is, after all, the important part of the question of car lubrication. It forms the goal to which the results of all the investigations in this branch are directed. The question is as to how many additional cars will an engine haul, or what reduction can be anticipated by the introduction of a new device, or a definite grade of oil, or, perhaps, a particular alloy for the bearing metal, in the cost of maintaining, satisfactorily, the lubrication of car journals. The efficiency cannot always, however, be seen in actual dollars and cents, without considering all the departments that are influenced. It is sometimes obtained through the reduction of anxiety of those in charge, by a lessening of the number of delays to trains, as well as a question of accommodation of the patrons. Considerable annoyance arises from heated journals, which are known to be expensive items of economy, if such can be, and is a true representation, when resulting from the use of ill-adapted or cheap material, or even of the design, of a small first saving with a large final expenditure.

Included in the cost of lubricating car journals, as now practiced, is the wear of the bearing metal,

quality and quantity of materials used in applying the lubricant to the journal, the cost and amount of the lubricant, the wear of the journal, and, still more important, the cost of the resistance of friction as represented in coal consumption. Many of these variables are dependent upon the relative location of the line of the road to the supply markets, as also the current market prices of the articles needed, the importance of which is not to be considered here, but rather that of the efficiency of the mechanical parts. A combination of all these elements is obtainable, giving the cost of maintaining properly lubricated car journals. This is also reducible to a condition representing the actual economy of oils of different quality and price, which is varied and experimented with probably more than any other single one connected with the subject—probably, too, because it is the easiest to handle.

To obtain an expression for the cost, let

B = abrasion in ounces of metal per journal per 1000 miles run;

b = cost of bearing metal per ounce;

O = quantity of oil in pounds consumed per journal per 1000 miles run;

o = cost of oil per pound;

W = quantity of waste consumed in pounds per journal per 1000 miles;

w = cost of waste per pound;

C = coal required expressed in tons per horse-power developed;

c = cost of coal per ton;

A = wear of axle, diametrically, in decimals of an inch per 1000 miles run

a = cost of axle wear, including the item of labor for finishing, per 1000 miles;
J = journal resistance in pounds per ton of load;
T = load in tons per journal;
d = diameter of journal in inches;
d' = diameter of wheel in inches.

The horse-power developed due to journal resistance would then be, per journal per 1000 miles run,

$$\frac{1000}{60} \times \frac{d}{d'} \times \frac{J \times T \times 5280}{33000} = \text{horse-power.}$$

The cost of lubricating one journal, including the cost of overcoming friction, would be represented by the expression

$$2.667 \frac{d}{d'} . CcJT + Bb + Oo + Aa + Ww = M.$$

If it is desired to compare two oils, there is but one item, that of the value of the waste, which can be left out of consideration. All the other functions enter as elements of the cost. The axle and bearing wear differs but little with two oils, unless there is considerable difference in their lubricating powers, so that, for comparison, the expression could safely be reduced to

$$\frac{M}{M'} = \frac{2.667CcJT + Oo}{2.667C'c'J'T + O'o'},$$

by which the relative value of two oils, M and M', can be determined. The object is to give, approximately, the values of the several functions entering as elements of cost of lubrication, and from them to obtain

some idea of the amount of this item when based on what is considered as average practice.

The coal consumption is determinable through the pounds resistance offered by the friction of the journal. It should be remembered, though, that it is pounds of traction, and when determining the coal consumed it should include the losses which take place between the boiler and the rear coupling of the tender. It is unfortunate that there is such a wide difference of opinion as to the pounds of resistance due to journal friction, a variation which can be accounted for only by the differences in the methods adopted by the various roads of lubricating journals and the nature of the tests. A close approximation for average service can be assumed, and a comparison can be made of the difference which would result from about as wide a variation in the conditions as is found in practice. Many people use the resistances that have been obtained from laboratory tests, but these do not give as close an approximation to the practical conditions as those derived from accurate dynamometer readings. The latest dynamometer diagrams show, with an engine of the consolidation type and with cars of 60,000 pounds capacity when running on a level tangent at a constant speed of fifteen (15) miles per hour, a resistance of $2\frac{1}{2}$ pounds per ton. This was with a heavy freight train, and the resistance would probably rise to $3\frac{1}{2}$ pounds per ton for lighter trains. Assuming the weight of the average freight train in the United States as 130 tons gives a basis from which an average figure can be obtained of the cost of overcoming journal resistance. With an average car-load of 15 tons this would give $8\frac{2}{3}$

cars per train of 130 tons. With cars having eight journals, this gives the load per journal of 3750 pounds. With 3 pounds resistance per ton would require, from page 54, 1.82 horse-power per 1000 miles run. This is for each journal, while the loss between the engine and the rear end of tender would be about 30 per cent, which would increase the power, when figured for the cost at the boiler, to 2.6 horse-power. With coal at $1.50 per ton on the engine, and a consumption of $4\frac{3}{4}$ pounds per horse-power, gives as average cost for the frictional resistance per journal per 1000 miles 0.926 cent. For comparison, let it be assumed that the oil selected is ill adapted to the purpose, as, for instance, that the conditions of the service are such that an oil of a resistance of 0.512 pound per square inch would be sufficient to meet the requirements, but in its stead one with a resistance of 0.652 pound per square inch had been previously selected and used. The cost per journal would then be 1.20 cents, representing an increase of over 29 per cent, indicating at once the advisability of selecting that oil which will give the least resistance, but which is, at the same time, capable of withstanding the maximum pressure.

Considerable variation will be found in the oil consumption, depending on the nature of the service. With passenger trains the high speed requires a more thorough oiling to dissipate the large amount of heat generated by the resistance of friction. In this case the heat must be carried off much more rapidly than in freight service, where any surplus heating by friction, arising from grit or other foreign matter, has more time in which to allow the journal to cool before reaching

that state where the bearing and journal seize. In passenger cars the effect is quite different and requires means for absorbing in as rapid a manner as possible any surplus heat generated. It would then seem that the difference in the consumption of oil in the two cases has arisen, not from a desire or necessity to reduce the coal consumption, but rather to prevent the annoyance arising from hot boxes; but when this annoyance has been reduced, it is too often assumed that the ideal condition of lubrication has been obtained. For instance, the oil consumption for passenger service has been known to be as high as 2.1 pounds per journal per 1000 miles, and as low, in the same service, as 0.55 pound. The first is an average condition, while the second is the case of a car that was being followed to compare the best results of woollen waste against a patented device, and indicates the possibilities in the way of oil consumption where closer attention or more systematic means are applied for lubrication. To further indicate the variation in oil consumption upon different roads, two lines were compared where the conditions of the service were as nearly equal as could be desired for a comparison. The oil consumption per journal per 1000 miles was, upon one, 0.354 pound and, upon the other, 1.05 pounds. From this, the difficulty of obtaining an average figure will be understood. We will, for an example and an approximation, assume it as one (1) pound per journal per 1000 miles in passenger service, and as 0.37 pound for freight cars. In the ratio of their relative mileages, this would give an average consumption of 0.5 pound of oil per journal per 1000 miles. At $2\frac{1}{2}$ cents per

pound, 1.25 cents would represent the value of the oil consumption.

When considering the question of bearings, attention is drawn to a very pretty point of economy. It is a point that is generally overlooked, while it affects quite as much the cost of the bearing as that of the metal abraded. It will be noticed that bearings are removed from service for two general reasons: first, where they are defective from overheating, or where they have become too thin from wear; second, from such other defects as require the removal of the axle. The second includes defective wheels, etc. In the first case the bearings are fit for scrap but nothing better, while under the second heading the bearings may be comparatively new or but partly worn out. In fact, it will be found by an examination of a number of bearings removed from service, especially where the hard metals are used, that an average life of the bearings would not give more than from one half to two thirds their total wearing thickness as having been abraded before removal. The weight of metal remaining is seldom fit for further service, so that the loss, representing the difference between the first and the scrap value of the remaining part, must enter as an element of the cost of the abraded metal. For example, taking a bearing which costs to produce, labor and material, 16 cents per pound and weighing 10 pounds, represents as the total value of the bearing $1.60. To compare extreme conditions, if two ounces are worn away in one case and eight pounds in the other, the value of the abraded metal, rating the scrap as one half the original value, would be as follows: where two ounces is abraded, the

value of abraded metal at $6.48 per pound, and where the eight pounds is worn away, a cost of 18 cents per pound. The latter would also give a greater average mileage per ounce of wear, as this becomes less rapid as the bearing is better seated to the journal. This is an extreme case, however, and in the absence of positive information we can safely assume, for approximate figures, the average condition as that where the bearing has worn fifty (50) per cent of its total weight. The first weight will be assumed as ten (10) pounds at a cost of sixteen (16) cents per pound. This gives the ounce value of the abraded metal as 1.5 cents. The wear per journal per 1000 miles is about 0.75 ounce, the value of which would be, on this basis, 1.12 cents. Objection may be raised to the rather low percentage of wear which is taken as the amount of abrasion of the bearing before removal from service, but an examination of the bearings that have been taken from cars and scrapped will show that they do not reach as high a percentage of wear as this, especially with the harder metals which is not due to any lower percentage of abrasion so much as to the more frequent removal from heating and similar causes. Take, for instance, the practice of using a cast-iron shell and filling it with a soft or so-called white metal. To eliminate the difference in the cost of the metal used for abrasion they will be assumed as of the same value, but instead of the bearing containing ten (10) pounds we will take it as consisting of seven (7) pounds of abrading metal, five (5) pounds of which, as with the solid bearings, is assumed as worn away before removal. The value of the abraded white metal would be 1.2 cents per ounce,

and for the hard metal, as before, 1.5 cents per ounce. The cast-iron shells are practically indestructible. The cost of refilling a shell with soft metal would be less than the expense of moulding the hard metal in sand. To go still further, let it be assumed that both bearings, as ready for service, are of the same weight, and that the cast-iron shell of the one weighs three (3) pounds. Assuming the same weight added to the hard metal for strength, this would represent, with cast iron at two cents per pound and for an equipment of 50,000 cars, an increased capitalization of $168,000 more than where the cast-iron shells and white metal are used. It should be understood that this represents the increased outlay which is necessary for equipping with the hard metal bearings, but does not include the reduction of the value of the abraded metal, nor the less cost of preparing the shell with soft metal bearing. It is figured on a conservative basis. A more detailed comparison of the two kinds of bearings would show still further in favor of the soft metal, and the argument would indicate the advisability of such for car service. The so-called wedge or liner which is used over the top of the bearing in the Master Car-builder's design of box may be considered a step in this direction.

The wear of axles will depend much upon the service, whether used under passenger or under freight cars; but when the axles are made of steel, and with wheels 33 inches in diameter, the wear is found to be about 0.0014 of an inch per 1000 miles. This figure is an average of a number of axles under passenger-equipment cars. Axles weigh some 375 pounds when

new, which, at a cost of 2 cents per pound, would be $7.50. Adding to this the labor of turning and preparing for service would make the first cost about $8.50. With an allowable diametrical wear or a diametrical reduction of one half ($\frac{1}{2}$) an inch reduces the weight of 4×8 journals fifteen (15) pounds, and a scrap rate of one-half a cent per pound would give the value of the axle wear per journal per 1000 miles as 1.877 cents.

The quantity of waste required per journal-box is about 1.349 pounds, from which an approximate average of 30,000 miles is obtained, representing, at $8\frac{1}{2}$ cents per pound, $11\frac{1}{2}$ cents as the value of this material, to which should be added the cost of the oil used in saturating the waste, as this is generally thrown away with the waste when the latter is removed. The amount of oil necessary to saturate the waste for one box is 8.4 pounds, which, at a rate of $2\frac{1}{2}$ cents, would make the total for the waste and the oil $32\frac{1}{2}$ cents, or 1.083 cents per journal per 1000 miles.

To summarize we find as follows:

Per Journal per 1000 Miles.	Cost in Cents.
Coal required in overcoming journal friction	0.926
Lubricant	1,250
Bearing metal	1.120
Axle wear	1.877
Waste and oil used in packing boxes	1.083
Total	5.751

It should be remembered that the coefficient of friction and the consequent coal consumption are dependent upon the nature of the service, and will be affected by a number of elements, such as the load carried, the nature

of the bearing metal, and the oil, together with other minor influences which have been mentioned under their respective headings. So, too, the item representing the oil consumption is dependent upon the grade of such material, as well as the amount which, in the judgment of the person in charge, is considered necessary for good lubrication; and is also influenced, to a large extent, by the design and maintenance of the journal-box.

Lately there has been a tendency to substitute a 36-inch wheel for those 33 inches in diameter, especially in passenger service. The small additional cost, all of which is included in the increased weight of iron, is more than balanced by the less wear and tear of the wheel, resulting from a less number of revolutions, so that the work of friction can be considered as reduced to an extent equivalent to the proportionate increase in diameter. This would affect the coal consumption, together with the wear of the bearing and axle, in each of which a proportionate decrease can be looked for.

Per Journal per 1000 Miles.—Wheels 36 inches diameter.	Cost in Cents.
Coal consumed in overcoming journal friction	0.849
Lubricant	1.250
Bearing metal	1.027
Axle wear	1.72
Waste and oil used in packing boxes	1.083
Total	5.467

As regards lubrication, the 36-inch wheel is 5 per cent cheaper than one of 33 inches diameter.

CHAPTER VIII.

HEATED JOURNALS.

If a journal becomes overheated, it is positive indication that some part of the mechanism is out of order, just as with the human body any sickness is proof positive that one or other of the organs is not performing its proper function. The moral effect in the two cases is also similar; for no one points with pride, unless it be on a competitive line, to a car that is passing and leaving behind it a streak of red flame and heavy obnoxious smoke from one or more journals, that have become hot.

It occasionally happens, and but occasionally, that journal-boxes receive too much care. This is apt to arise with trains in heavy service and in which delays attract unusual attention. With such trains it has been known that too much care has been used in the attention given to the boxes, especially in the too frequent use of new waste.

The examination of a bearing that has been removed from an overheated journal will seldom give sufficient trace of the cause. No attention should be given to the scaling found on such bearings, as it is simply a result and seldom indicates anything more than that the bearing has been in contact with the journal and heated by the friction so produced until the scaling resulted.

The cause of most of the hot boxes can be reduced to two general headings.

1st. Those produced by mechanical defects.

2d. Those due to defective lubrication.

The first is of such a nature that the construction can generally be analyzed and corrected. It may be in the design, such as the method of distributing the load, or imperfect protection from dust and oil. Or it may arise from poor quality of bearing metal, waste, or oil. These as such require the proper course for their elimination, although a slow process, and sometimes an expensive one, especially when it becomes necessary to change the design of the box and the size of journal, etc. It sometimes occurs that the trouble can be obviated by the use of some mechanical turn, such as using a lead lining where the load is not well distributed. One case is known where a re-designed journal-box which became necessary from more severe service gave a remarkable reduction of heated journals. The percentage of old and new journal-boxes in service was about in the ratio of four (4) to one (1); while the number of heated journals arriving at a specified point within a given length of time gave the respective ratio of one hundred (100) to three (3), before and after the change was made in the box. The cars having the newly designed box with large journal were placed in the heaviest and most severe service.

Heated journals have been known to have occurred from a steady and heavy application of the brakes, referring to those applied by compressed air. When tracing this cause of heating it has been found that a new bearing, or one the radius of which is considerably

larger than that of the journal, was used, and the amount of clearances between the pedestal and the journal-box, was greater than that between the sides of the bearing and the box, so that a slight raising of the bearing resulted from the box pressing heavily upon one side of the bearing. In this way, the edge of the bearing is thrown against the journal, when all the pressure is taken by a very small area; and, if the brakes are kept on for sufficient time, more or less heating, but not always a severe condition, will result. It is not uncommon for heating to occur from the long fibres of new waste working between the bearing and journal, and especially before the bearing has worn down to its whole arc of contact.

Under the second head are included those caused by the use of poor quality of oil or waste and those that are due to improper attention. These arise from the lack of sufficient oil for lubrication, but more particularly where the waste next the journal has become so deteriorated from foreign matter as to prevent good lubrication. The pasty condition of the top of the waste, more particularly where the animal oils are used is due also to their oxidation and their effect upon the bearing metals, the extent of which was indicated in the chapter on Bearing Metals.

The preventive for heated journals, coming under the second heading, would be a systematic method of attending to the lubrication. By this is meant that after the car had made a specified mileage, remove the waste from the boxes, which, instead of being thrown away, can be cleaned and thoroughly saturated with oil, when it will be ready to be again placed in boxes

for lubrication. The important point is to break up the hard, gummy surface which forms on the top of the waste, and this can only be accomplished by removing the waste from the box. It is probably safe to say that the method of attending to the lubrication of car journals on most if not all of the railroads of the country to-day is about as follows. The boxes are packed and oiled when the car first leaves the shop. After it is in service it is occasionally, or it may be frequently, oiled; by which is meant the front of the box is opened and a small amount of oil is poured in upon the top of the waste at the front. The box is allowed to run in this way, with the little additions of oil, until it is removed either for the renewal of a worn bearing, changing the wheels, or for a heated journal. The top of the waste in the mean time has become saturated with foreign matter, making a pasty condition which is aggravated where the animal oils are used on account of their oxidation, and probably more or less from the action of the acids upon the bearing metal. This condition of the top of the waste not only acts as a poor lubricant next to the journal, but prevents the oil at the bottom of the box from reaching the journal. Of the fresh oil poured into the box from time to time, a small part is retained by the waste, but a hasty examination will indicate that a large part is lost and thrown upon the ties. It has often been thought that a systematic method of removing the waste, so as to break this hard or pasty surface, would prove a very profitable investment. If the waste, after cleaning, contains too much grit or foreign matter to prevent its further use, let the oil, which in car service is never

what is called worn out, be extracted from the waste and re-used, thoroughly cleaning it and straining to remove foreign matter.

Until more uniformity in the design of journal-box and handling of freight cars can be obtained than now exists, the above would, of course, apply only to passenger-equipment cars.

It should be remembered that poor lubrication is represented in cost by actual dollars and cents, the extent of which is shown in the chapter on Cost of Lubrication.

Like many troubles, a large percentage of the hot boxes could be prevented by the proper application of a handful of oil, provided such is done before the surfaces of the bearing or journal have become injured.

The present method of lubricating car journals is by no means an imperfect one when the best is made of it, and we should be careful not to attribute the failures arising from a lack of proper attention to the method.

APPENDIX.

EXPERIMENTS ON THE LUBRICATION OF AXLE-BEARINGS.

By E. CHABAL, in *Revue Générale des Chemins de Fer.*

FROM 1871, the period at which the Paris-Lyons-Mediterranean Railway Company abandoned grease for lubrication for the axles of carriages and wagons, and adopted oil, they, up to 1885, had made use of bronze bearings and of colza-oil (pure in summer, with an addition of 10 per cent of shale-oil in winter).

In 1885 the trials made by other companies in the use of white-metal bearings and mineral oils induced them to make similar experiments, and also to find out whether the substitution of wool for cotton for the lubricating wicks would not be advantageous. They consequently made a series of tests to compare the results of using (1) white-metal bearings lubricated with mineral oil, (2) bronze bearings with mineral oil, and (3) bronze bearings with colza-oil.

The following is a *résumé* of the tests made:

A. Tests made from 1886 to 1889, to measure directly the resistance of wagons to traction by means of allowing them to gravitate down a gradient and meas-

uring the time taken. These tests have enabled the following to be compared:

1. The resistances of wagons having different kinds of bearings with different lubricating-oils.

2. The resistances of two wagons coupled together and one running alone.

3. The resistances of open and covered wagons.

4. The resistances of wagons on two axles and on three axles.

B. Tests made from 1889 to 1890, to measure directly the resistances of wagons to traction, in drawing coal-trains divided into two parts of 300 tons each; this division is made only for the purpose of comparing the influences on the two parts, and measuring the resistance of each by means of two dynamometer cars, and thus also enabling the resistances of wagons placed at the head of a train to be compared with those at the rear.

C. Abstracts made from 1887 to 1889 on a certain number of carriages running in service with bearings made of pure metal and bronze, giving the mileage run over.

D. Abstracts made in 1891 of the consumption of oil on passenger trains mounted on bearings of pure metal, and lubricated (1) with colza-oil, (2) with mineral oil.

E. Tests made in 1891 to determine the capillarity of the staple for lubricating-wicks, whether they be of wool or cotton, and according to what oil is employed.

F. Tests made from 1888 to 1891 on carriages in service, to compare the lubricating-wicks of cotton and wool.

G. Tests made in 1890 on vehicles running by themselves with two and three axles.

The following is a summary of the conclusions arrived at:

LUBRICATING-WICKS.—The tests made to compare the woollen wicks with those of cotton in regard to the facility with which they supply the oil have shown a superiority of delivery of from 50 per cent to 100 per cent in favor of the woollen wicks. It was also found that the renewals of the woollen wicks were only 68 in number compared to 100 of the cotton ones, and that the woollen wicks were less liable to firing. Notwithstanding the higher price of the woollen wicks, it was found economical to use them, and since May, 1893, the Paris-Lyons-Mediterranean Company have adopted them entirely.

BEARINGS.—The result of the tests made showed that the wear of white-metal bearings was 50 per cent less than in the case of bronze bearings. The tests also showed that, by the use of white-metal bearings, a diminution of 20 per cent on the resistance of fully-loaded coal-wagons, forming trains weighing 300 tons, travelling at speeds of 16 miles to 26 miles an hour, was given; that, as the speed increased, this gain was diminished, but remained always 5 per cent less. As a consequence of these tests, the Paris-Lyons-Mediterranean Company in 1893 abandoned the use of bronze bearings for carriages and wagons, and adopted white-metal bearings.

LUBRICANTS.—The tests made by abandoning carriages to themselves on a gradient have fully justified the rejection by nearly all the railway companies of

grease and the adoption of oil. Grease gave, for carriages isolated and mounted on bronze bearings, an increase of resistance per ton of:

25 per cent in comparison to mineral oil at low speeds (19 miles an hour);

40 per cent in comparison to colza-oil at low speeds (19 miles an hour);

3 per cent in comparison to mineral oil at high speeds (38 miles an hour);

14 per cent in comparison to colza-oil at high speeds (38 miles an hour);

The increase of resistance would be greater in ordinary trains than indicated above for isolated carriages. From these same tests, combined with those made by means of the dynamometer-cars, it was found, in comparing colza-oil, mineral oil, and mixtures of these two, that colza-oil is more advantageous than mineral oil, and that the mixtures are classed between the two. Taking white-metal bearings, colza-oil, with an addition of 10 per cent of shale-oil, appeared to be very nearly equal to pure colza-oil in relation to non-resistance to traction; pure mineral oil gave in relation to pure colza-oil an increase of resistance per ton of 15 per cent for trains of 300 tons, composed of fully-loaded coal-wagons, and running at speeds of 16 miles to 26 miles an hour. The mixtures of mineral and colza-oil gave more resistance than pure colza-oil, and the increase of resistances were, in the same trains:

13 per cent for the mixture of 75 per cent of mineral oil and 25 per cent of colza-oil;

7 per cent for the mixture of 50 per cent of mineral oil and 50 per cent of colza-oil;

3 per cent for the mixture of 25 per cent of mineral oil and 75 per cent of colza oil.

It was also found that in summer the consumption of colza-oil was only 0.8 of that of mineral oil. The tests were not made in winter, but it is presumed that then the consumption of mineral oil would be less. As a result of the tests, the Paris-Lyons-Mediterranean Company abandoned in 1891 the use of mineral oil, and adopted exclusively colza-oil with an addition of 10 per cent of shale-oil, the latter having the advantage of thickening less at a low temperature. The author estimates that in round numbers his company spent in 1890 £640,000 in coal for the traction of their trains, and used 766 tons of lubricants. If mineral oil had been used in place of colza-oil, £64,000 more would have been expended on coal and £12,250 less on oil, thus justifying on the side of economy the choice of colza-oil.

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